Magnetoresistive Perovskite Ruthenates

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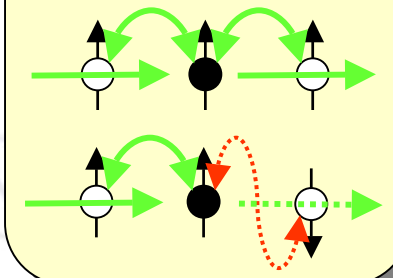
$SrRuO_3$
FM metal

Doping with
$LaFeO_3$
AFM insulator

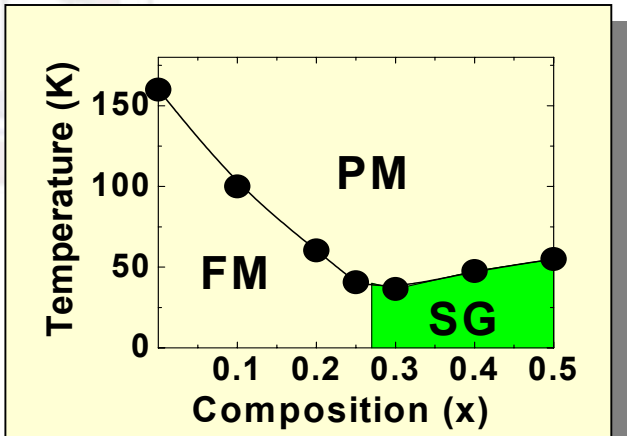
$(Sr_{1-x}La_x)(Ru_{1-x}Fe_x)O_3$

- First large magnetoresistance observation in spin glass systems
- No mixed valences in materials
- Atomic-scale spin valve mechanism proposed

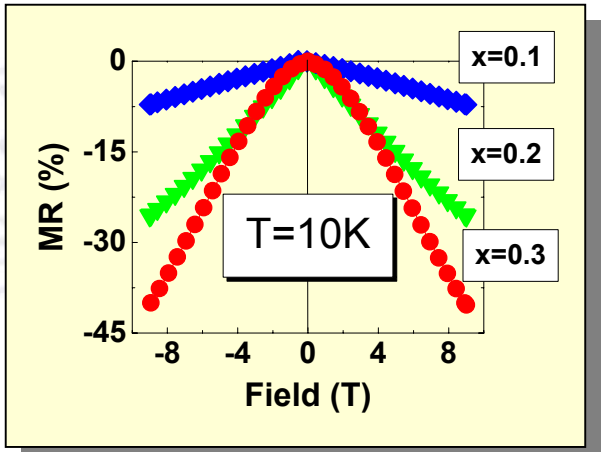
Atomic spin valve



Magnetic phase diagram



Magnetoresistance under applied field



Colossal magnetoresistance (CMR) has been extensively studied in Mn-containing perovskites. This class of materials have mixed valence on the Mn site (Mn3+and Mn4+), and they become ferromagnetic and metallic at low temperatures. Since most oxides are actually antiferromagnetic and insultating, the discovery of such materials was a novelty in the1950's, leading Zener's to propose that double-exchange interaction between d-electrons of Mn is the responsible mechanism. Later, it was found that the an external magnetic field can have a large effect on the onset of the phase transition, causing large changes in electrical resistance as the material undergoes the insulator-metal transition. This effect is called colossal magnetoresistance and it has occupied the attention of numerous solid-state physicists and chemists in the last 10 years.

We now show for the first time that the same large magnetoresistance can also be observed in ruthenates that do not contain Mn. These materials have no mixed valency, and there is no ferromagnetic transition. In fact, the new materials lack long-range magnetic order altogether and should be considered as a spin glass. The magnetoresistance in these materials is rather linear with the field (see property diagram on the lower right), making it suitable for applications for field sensing.

These new materials were obtained by introducing magnetic dopant LaFeO3 into a parent perovskite compound SrRuO3. (See flow chart in the center left.) The parent compound is ferromagnetic and conducting, but the dopant compound is antiferromagnetic and insulating. The presence of the latter causes magnetic frustration in the alloys and establishes a spin glass. (See phase diagram on the upper right, FM=ferromagnetic, PM=paramagnetic, SG=spin glass.) We have conducted experiments (DTA and synchrotron XANES) to verify that there is no mixed valency in the alloys.

Large magnetoresistance was found at low temperatures in compositions that are in the spin glass region but close to the spin-glass/ferromagnetic border. (See figure on the lower right). This effect is larger at lower temperature, and is absent once the ferromagnetic region is entered. One possible application envisioned is a thin film magnetometer that is inserted in the superconducting magnet, which is held at the liquid He temperature. Such magnets are in wide use in the hospitals (MRI) and laboratories (magnetometers.)

We propose that the new magnetoresistance is associated with the magnetic impurities (Fe3+), which operates as atomic spin valves. (See figure in center bottom). When its spin aligns with that of neighboring Ru4+, current can pass through by electron/hole hopping. When it does not, the current is blocked. This mechanism is rather similar to the one found in GMR memory devices that uses stacks of several nm-thick thin films of different magnetic orientations, but it apparently also operates at the atomic level. The critical considerations are (a) some magnetic correlations must exist prior to field-induced alignment, hence a spin glass; (b) the energy level of neighboring ions and the spin valve must be close enough to allow a large transition probability for electrons, hence Ru4+ and Fe3+; (c) large magnetic susceptibility of the system favoring field-induced alignment, hence the borderline composition between spin-glass and ferromagnet.